Dilepton Physics with the PHENIX Experiment at RHIC

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Columbia University

Workshop on Hard Processes and RHIC Physics
Los Alamos Nat. Lab, 12-16 June, 2000

Signatures of Plasma Formation

★ **A. Deconfinement**
- Suppression of quarkonia (J/ψ, ψ’,Y) states

★ **B. Thermal Radiation**
- Prompt γ, γ^* to e^+e^-, $\mu^+\mu^-$

★ **C. Chiral Symmetry Restoration**
- Disappearance of ρ state
- Mass, width, B.R. modification of φ

★ **D. Strangeness, Charm and Bottom Production**
- Nuclear effects, fast thermalization

★ **E. Jet Quenching**
- High pt jets via leading particle

F. Equation of State
- Hydrodynamic flow, correlations, coalescence

★ Can be measured with leptons

Lots of Physics

Melting of the ρ

Deconfinement by J/ψ suppression

Chiral Symmetry Restoration shifting ϕ mass

Thermal Production of Charm

Baseline with Y

Relativistic Heavy Ion Collider

Au + Au collisions at cms energy <u>**40 TeV**</u> (200 GeV/u)

- 10^{12} collisions per year

p + p collisions at <u>**500 GeV**</u>

- polarized beams

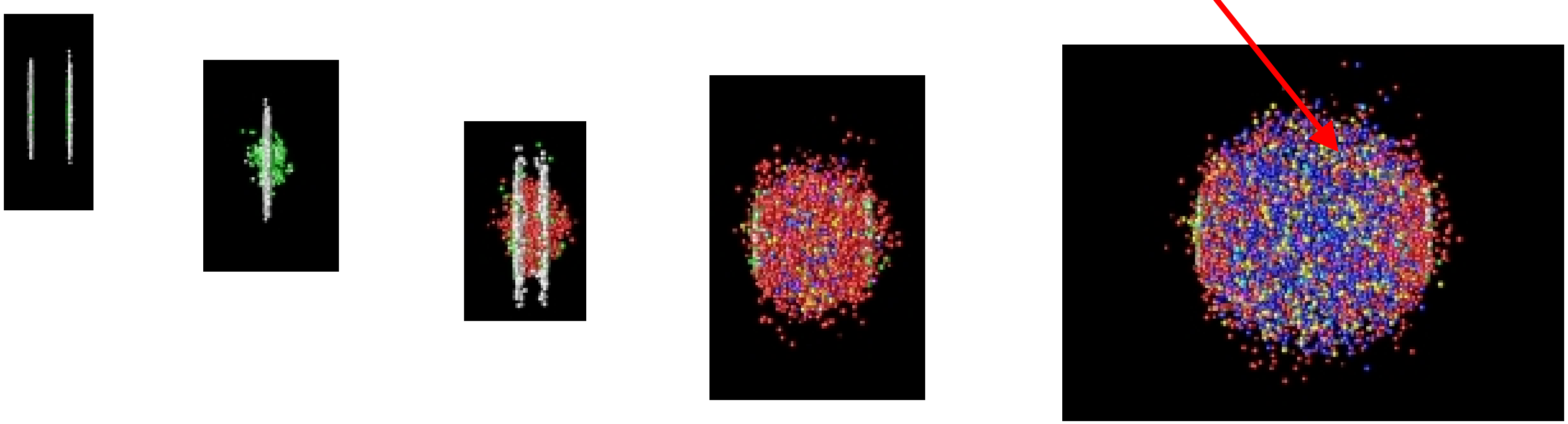
Everything in between

Experimental Challenges

Violent collision of Au + Au nuclei at ~ 40 TeV

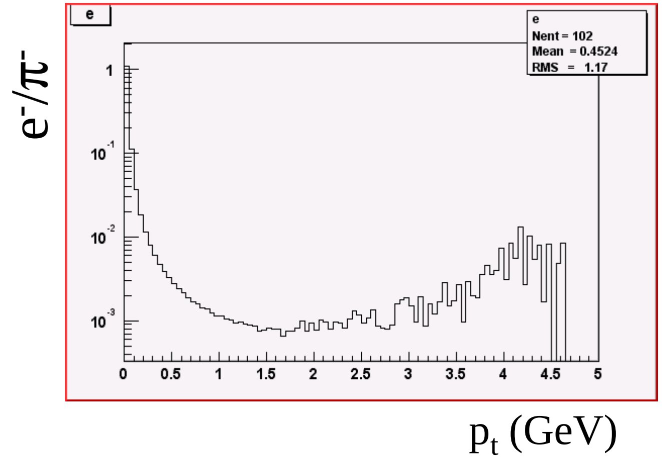
Thousands of particles produced (mostly hadrons)

Here is the muon you are interested in



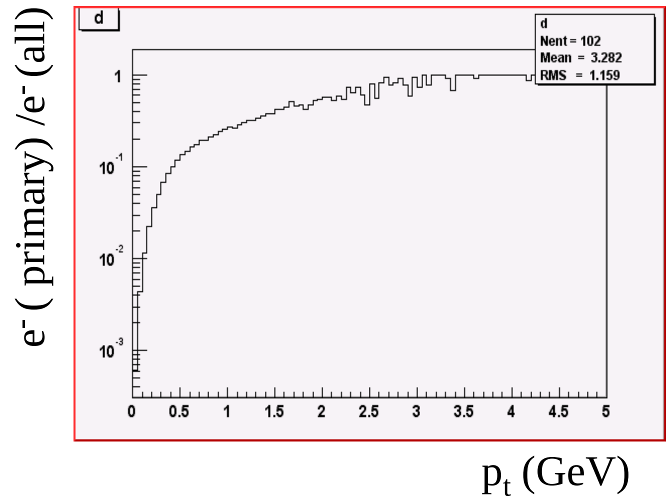
More Experimental Challenges

- Thousands of π produced in the collision
- Ratio of π to electrons is ~ 1000 : 1
- Must reject π at the level of **10^{-4}** over a broad range of momenta to cover the necessary physics



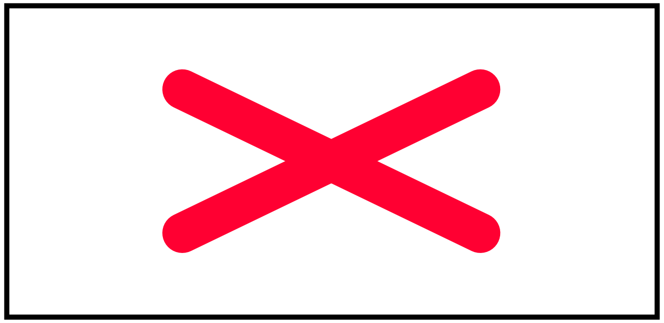
- Also, once one has a good lepton sample, there are many “background” leptons that must be rejected or subtracted out

$\pi \rightarrow e^+ e^- \gamma$	$\gamma \rightarrow e^+ e^-$
$\pi \rightarrow \mu\nu$	$K \rightarrow \mu\nu$



Even More Experimental Challenges

CERN-SPS at 17.4 GeV/u



J/ψ in PbPb: σ ~ 2 mb
Collision rate: 3 x 10^6 Hz
Running/year: 5 x 10^6 s

Bottom Line: 5 x 10^9 / year

RHIC at 200.0 GeV/u

J/ψ in AuAu: σ ~ 50 mb
Collision rate: 1 x 10^4 Hz
Running/year: 2 x 10^7 s

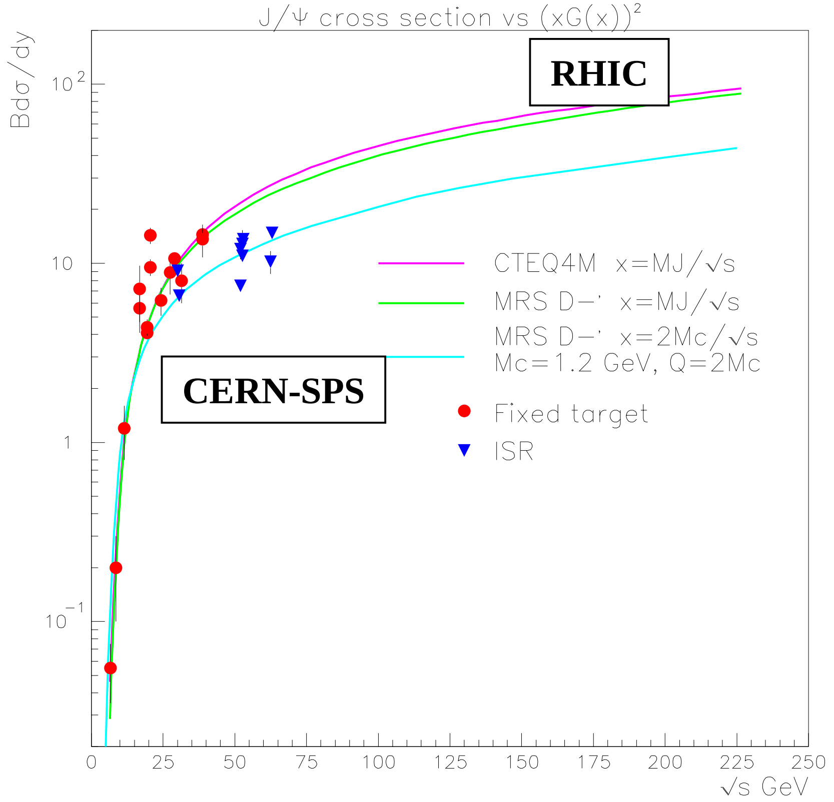
Bottom Line: 2 x 10^9 / year

* Branching fraction, acceptance, efficiency reduce the number to ~ 10^5-10^6 / year

Threshold Effects

RHIC is ideally situated for exploring charmonium as a probe of dense nuclear matter.

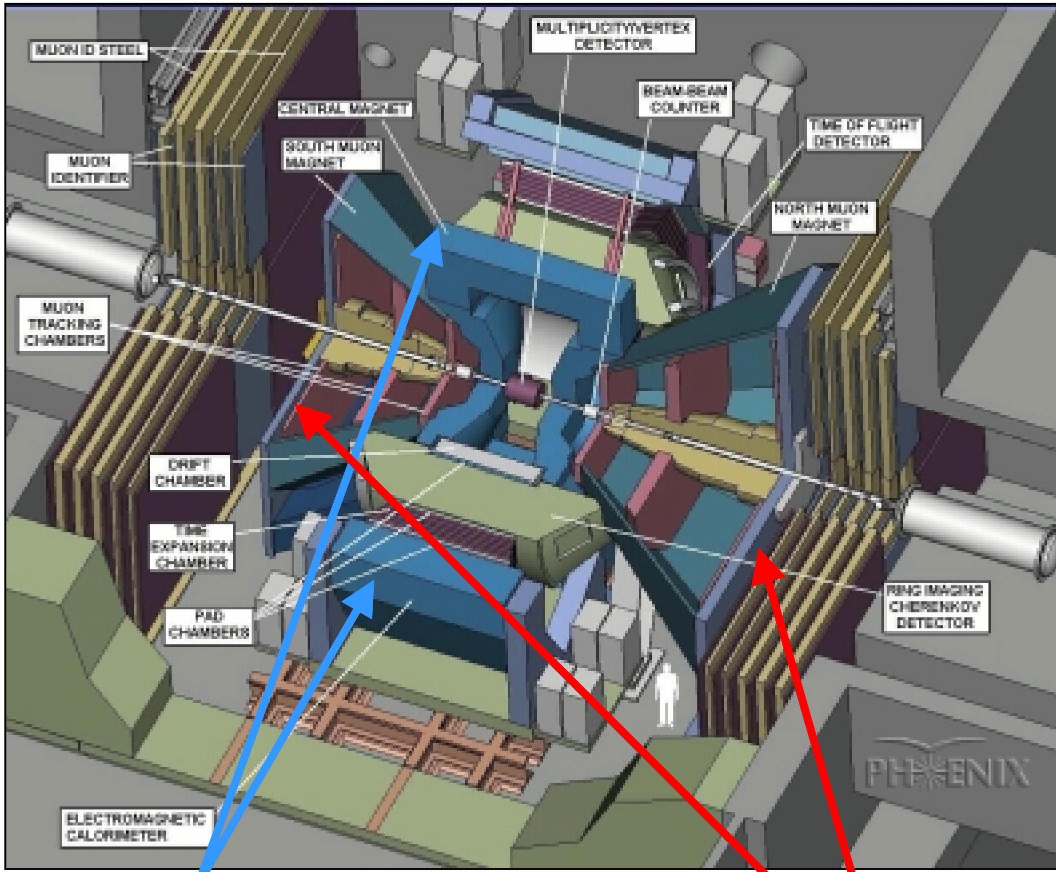
J/ψ remains a "rare" probe, but measurable with fine binning as a function of centrality, pt, and collision energy.



PHENIX Experiment

PHENIX - only RHIC experiment specifically designed to measure rare probes in the lepton and photon channels.

It can sample all Au + Au collisions up to 10 times RHIC's design luminosity

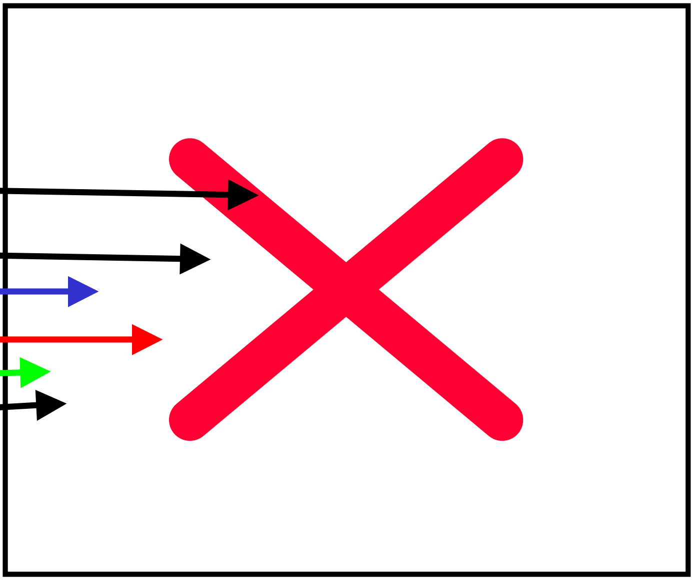


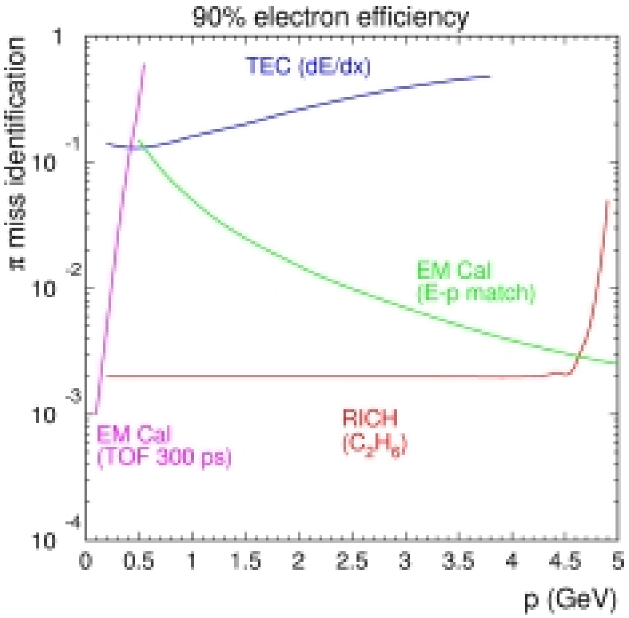
Two central electron/photon/hadron spectrometers

Two forward muon spectrometers

Meeting the Electron Challenge

- Central Arms Cover $-0.35 < \eta < 0.35$
- Charged particle tracking
  - Drift Chamber
  - Pad Chamber
  - Time Expansion Chamber
  - Ring Imaging Cherenkov Counter
  - Electromagnetic Calorimeter
  - Time of Flight Hodoscope

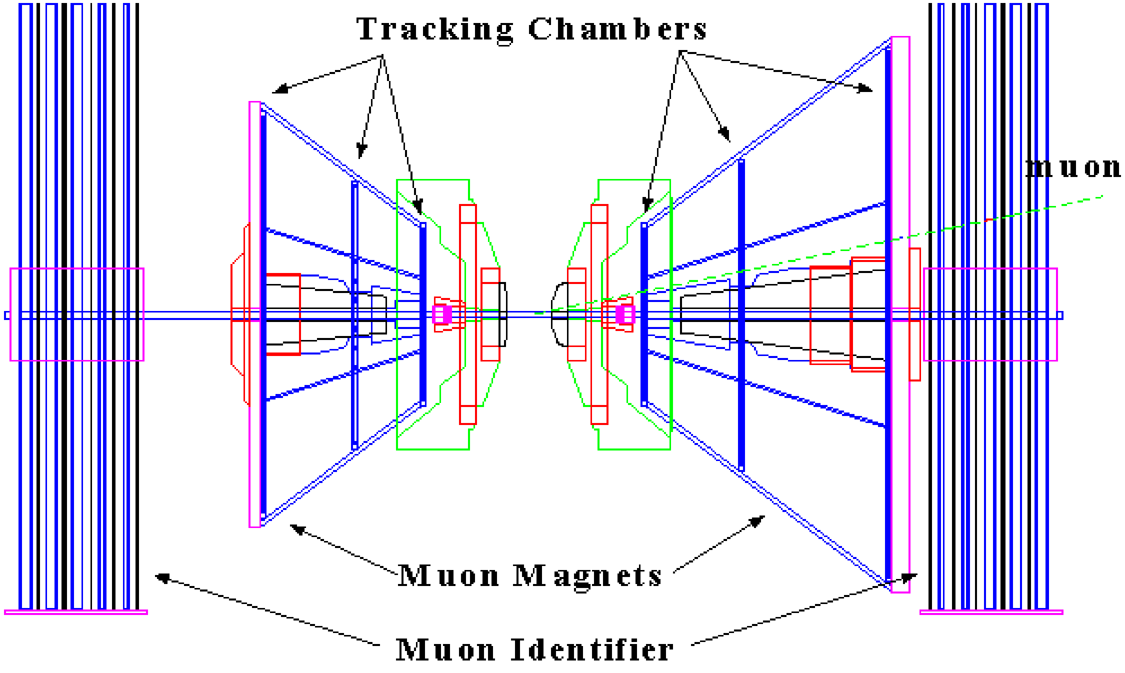




Hadron rejection at 10^4 level in Au+Au central collisions over a broad range in momenta requires many detector technologies

Meeting the Muon Challenge

- Muon Arms Cover $-1.2 < \eta < 2.4$ (North)
- $-1.2 < \eta < 2.2$ (South)
- Tracking with 3 stations of chambers in magnetic field
- Muon Identification with 5 layers of steel absorber and Iarocci tubes
- Low energy cutoff at ~ 2 GeV



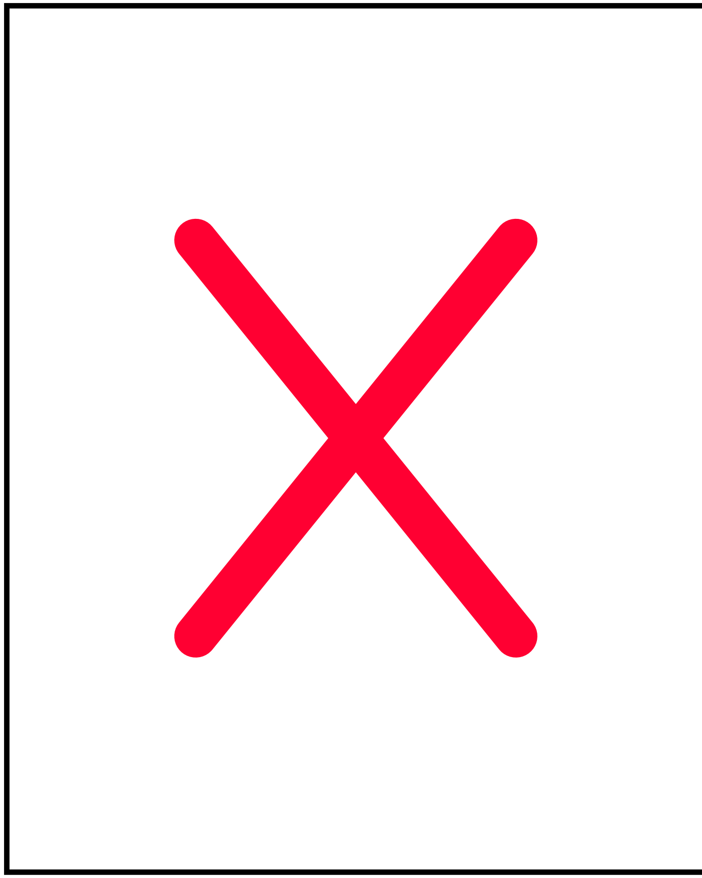
Meeting the DAQ Challenge

Designed to handle data at up to 10 times RHIC design luminosity

Au + Au collision rate ~ 13 kHz
p + p collision rate ~ 8 MHz

Data Collection Modules are designed for a maximum rate of 25 kHz or
~ 50 Gigabytes per second.

High level triggers and zero suppression must reduce this to 250 Au+Au or 2900 p+p events to tape per second.



Charm and Beauty

In order to understand J/ψ yields, we must understand charm production

- Total production rates
- Shadowing (nuclear effects)
- Jet quenching in plasma

Direct reconstruction of open charm is optimal.

One can also measure open charm and bottom contributions through **single leptons** and **lepton pairs**.

$D^0 \rightarrow K^- \ \pi^+$

$D^0 \rightarrow K^- \ e^+ \nu_e$

$D^0 \rightarrow K^- \ \mu^+ \nu_\mu$

$B^0 \rightarrow D^- \ \pi^+$

$B^0 \rightarrow D^- \ e^+ \nu_e$

$B^0 \rightarrow D^- \ \mu^+ \nu_\mu$

$D^0\overline{D}^0 \rightarrow \mu^+\mu^- \ K^+ K^- \nu_\mu \nu_\mu$

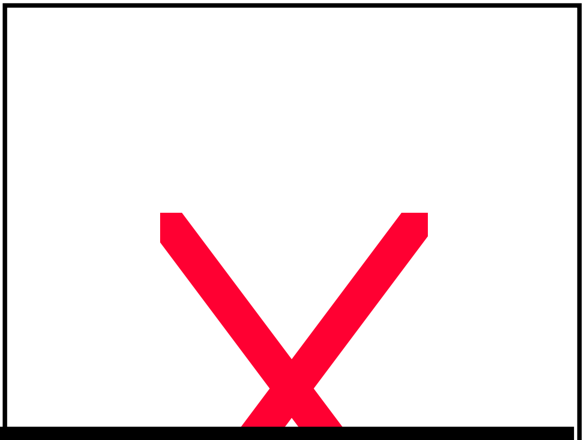
$D^0\overline{D}^0 \rightarrow e^+e^- \ K^+ K^- \nu_e \nu_e$

$D^0\overline{D}^0 \rightarrow \mu^+e^- \ K^+ K^- \nu_e \nu_\mu$

Cross Sections?

In initial parton-parton collisions we create q-qbar pairs.

The cross sections for these processes are not so well known at this point.



Charm cross section in p+p: ~ 200-400 microbarns

Bottom cross section in p+p: ~ 2-4 microbarns

And the momentum space distribution must have some real uncertainty too. K factors are somewhat funny since NLO calculations show changes in distribution not just normalization.

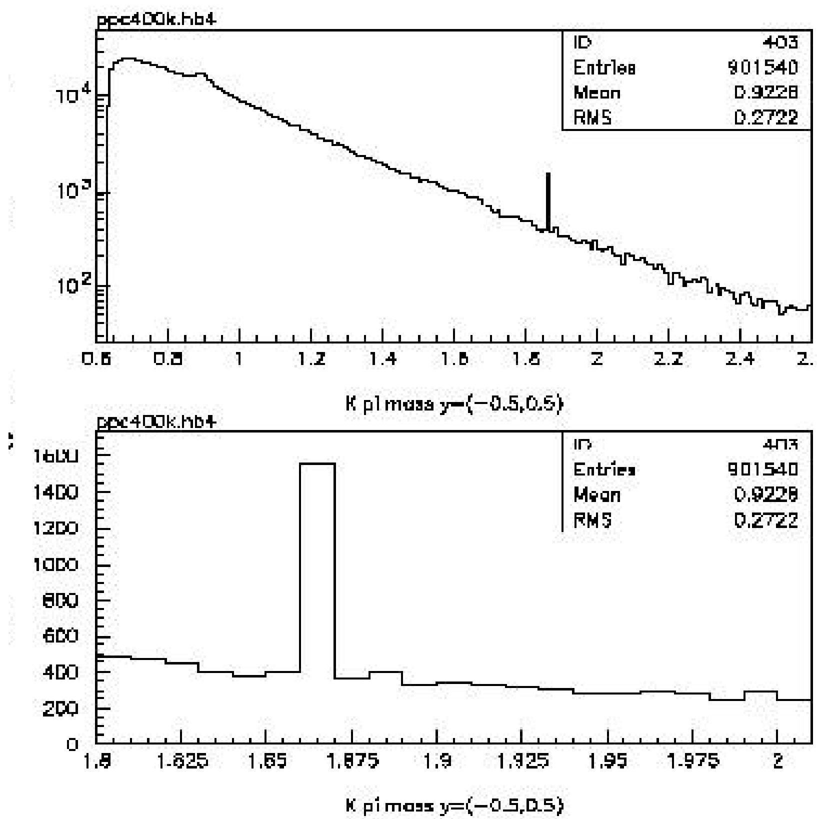
Direct Measure of Open Charm

Large combinatoric background in the hadronic channel.

$D^0 \rightarrow K^- \ \pi^+$

Silicon Detector to measure displaced vertex not included in PHENIX, but also looks difficult for any experiment due to high multiplicity.

Matching of all pairs with a lepton tag for the other charm partner may work for p + p, p + A, ….?



Kπ invariant mass distribution in p+p events with charm pair, calculated with PYTHIA. A peak at 1.8 GeV is a signal of $D^0 \rightarrow K\pi$ decay.

Study by Y. Akiba

Single Leptons

Electrons in PHENIX

Dalitz and conversions→ e-

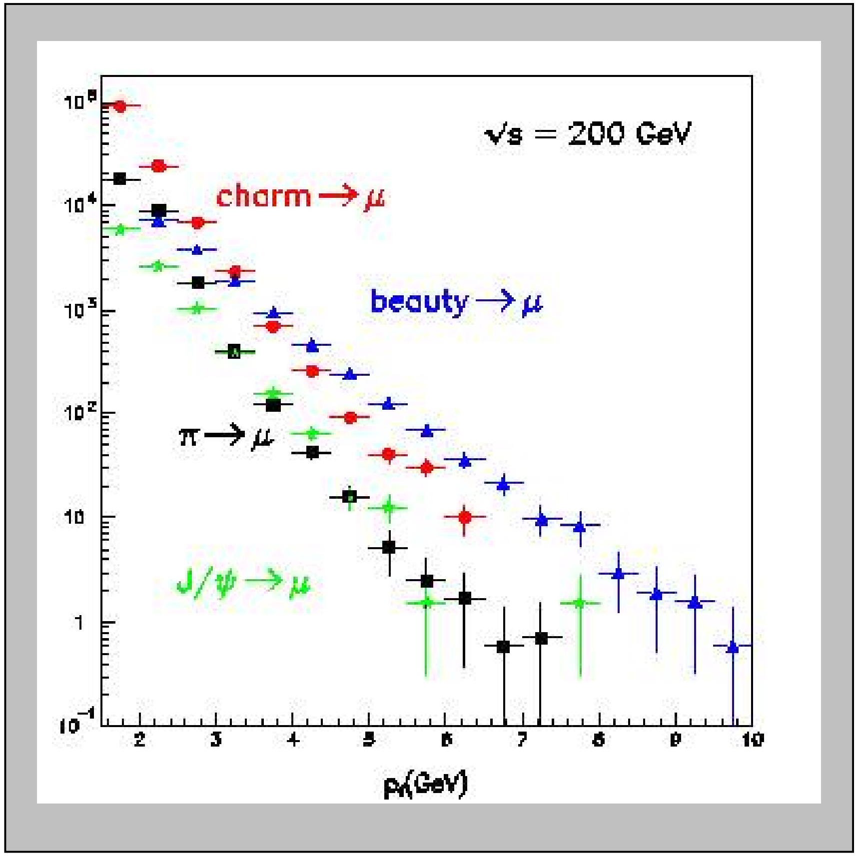
charm→ e-

beauty→ e-

Drell-Yan→ e-

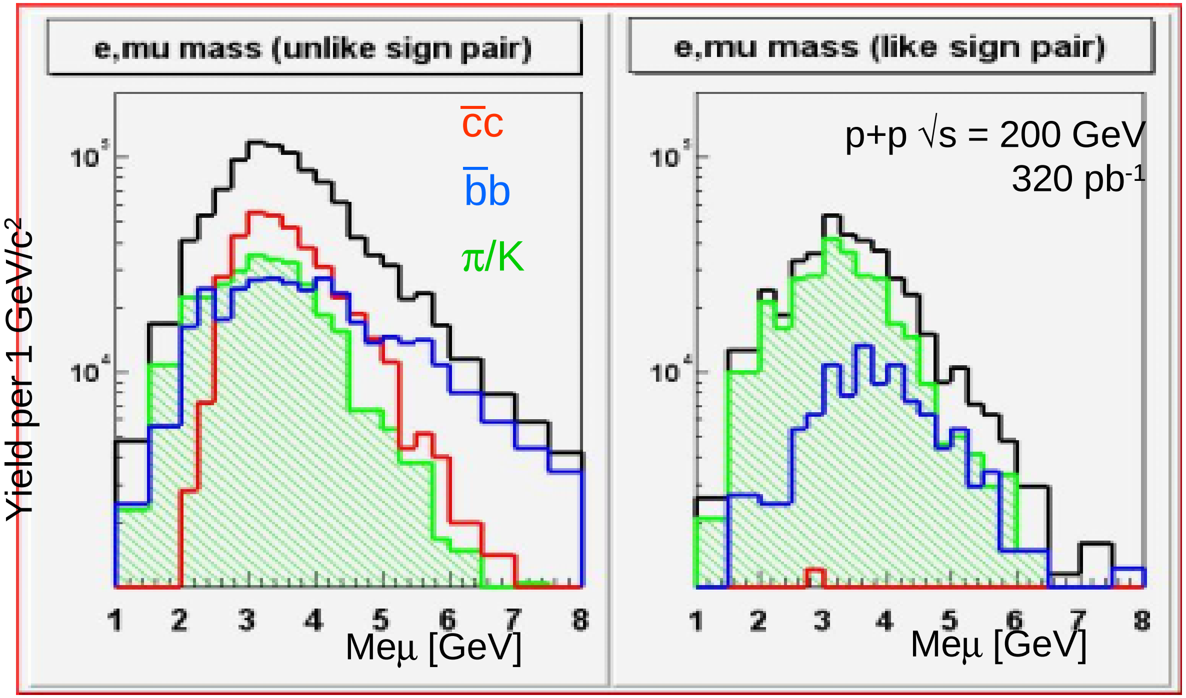
Study by Mickey Chiu, JLN

Muons in PHENIX



Study by M. Brooks, J. Moss

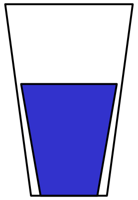
Electrons and Muons



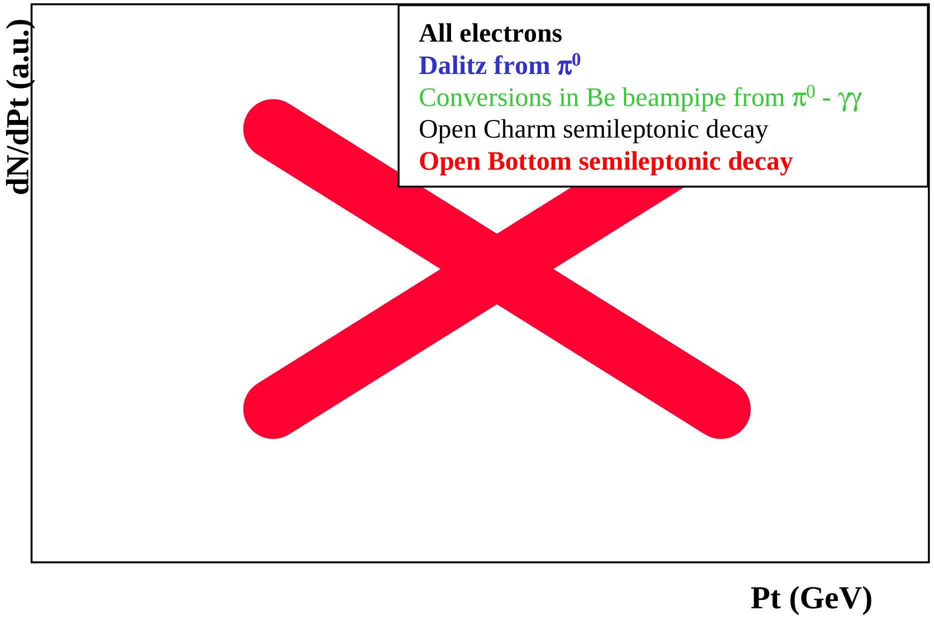
- Excellent additional check on charm and beauty production.
- Different signal spectra and background contributions.
- However, also different acceptance and efficiency issues.

Maybe too much of a good thing?

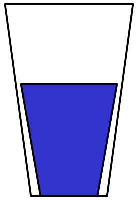
The single lepton spectra has a wealth of information.

The glass is half full 

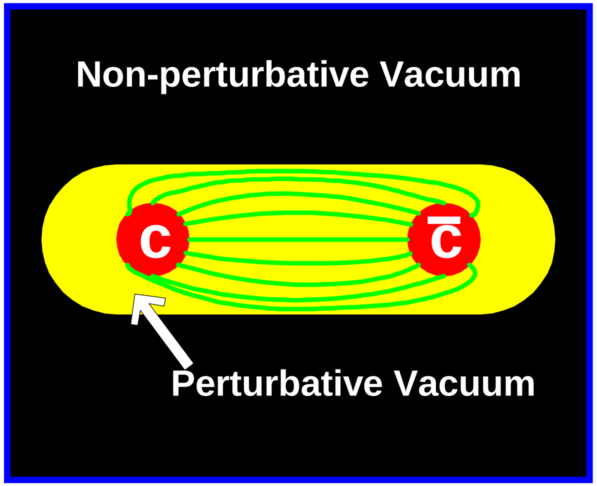
• Yield reflects partonic charm and bottom cross section, nuclear effects, and possible thermal production.
• Shape reflects pdf's, shadowing, energy loss, ………...



Too many unknowns and not enough equations?

The glass is half empty 

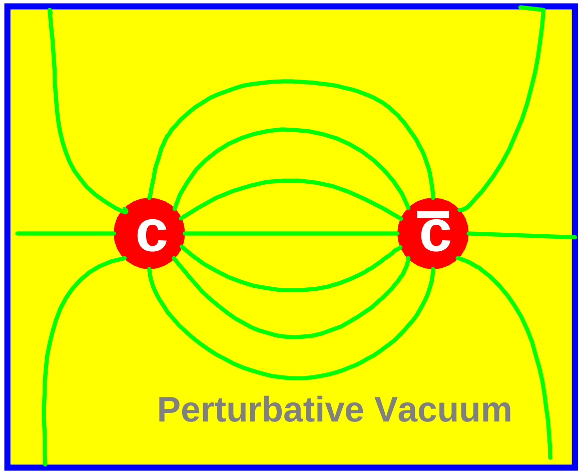
J/ψ Suppression

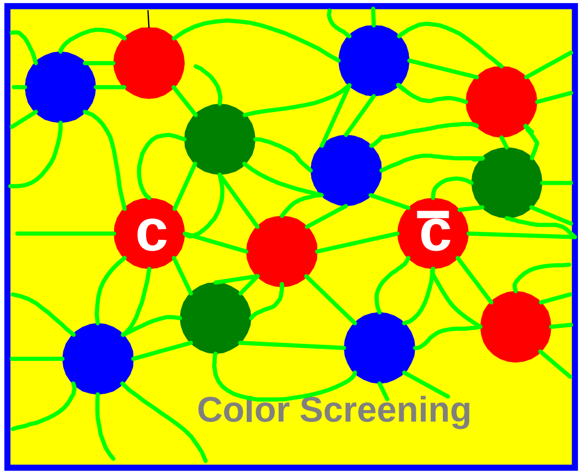


Vector meson J/ψ

– bound state of a charm quark and anti-charm quark

The pair feels an attractive force and can form the above bound state. However, in the middle of a quark-gluon plasma the attractive force is screened.

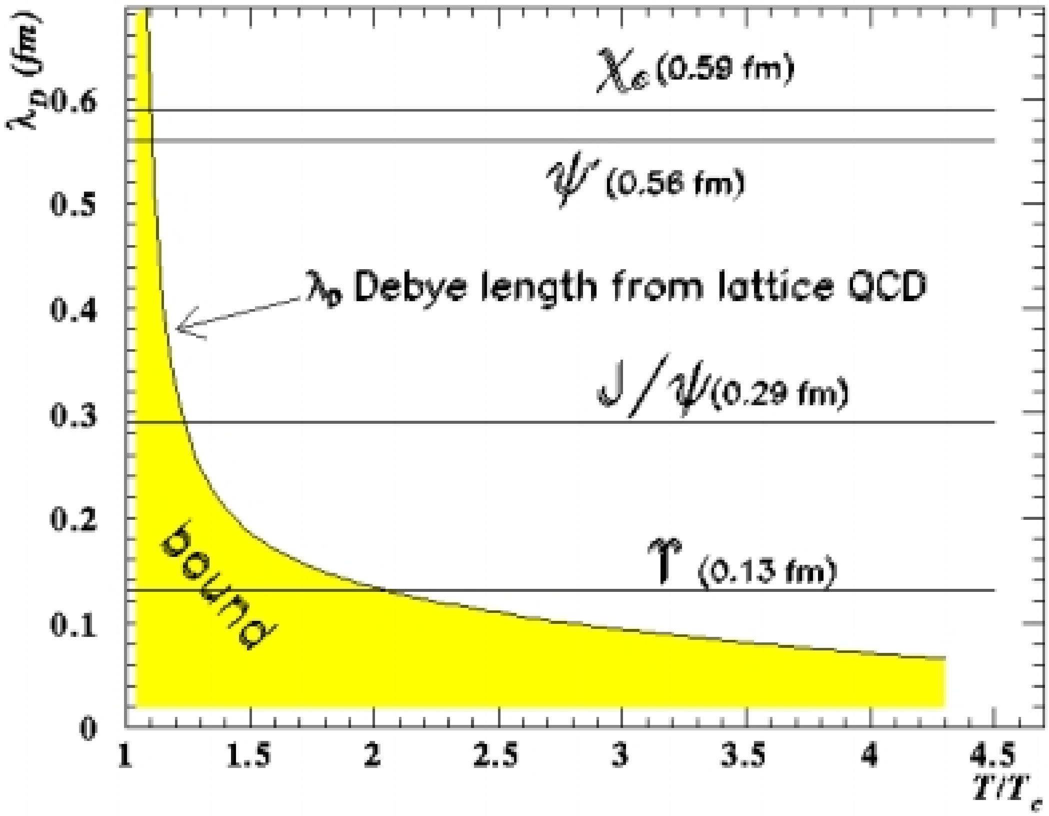




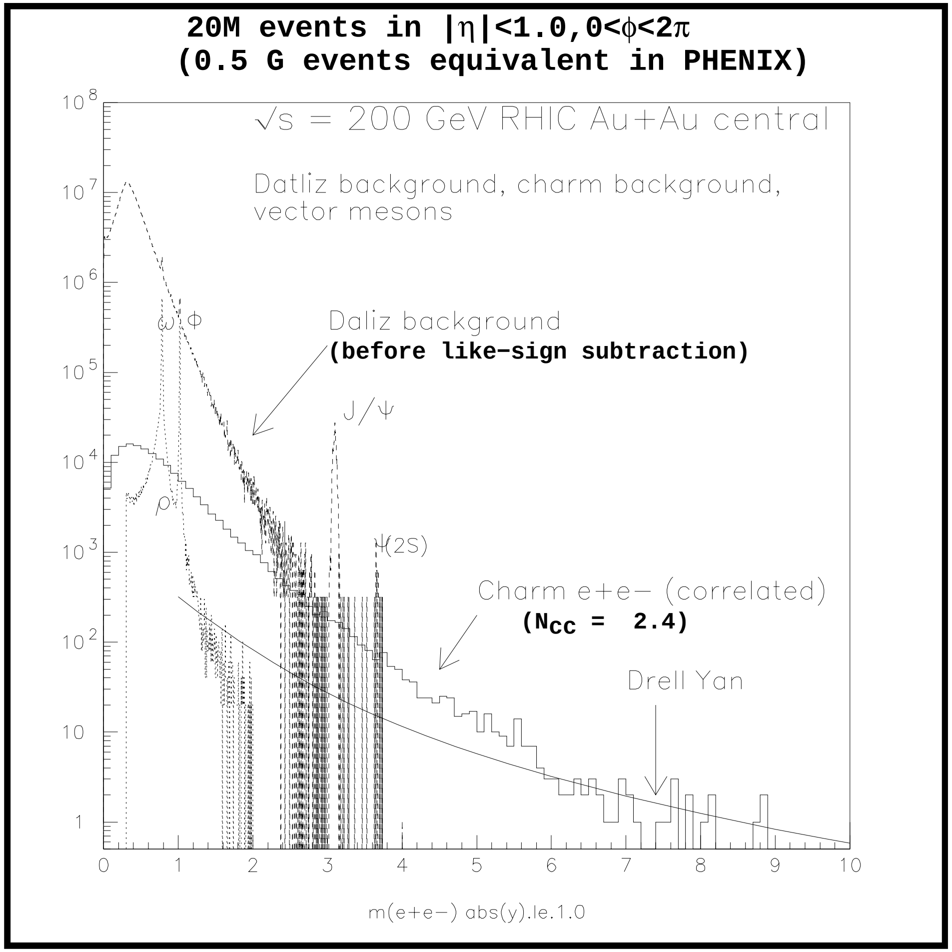
QCD Thermometer

Hadrons with radii greater than ~ λ_D will be dissolved (suppressed)
Debye screening length λ_D ~ 0.5 fm at a temperature T = 200 MeV

As the temperature is raised above the critical temperature, one should see the sequential suppression of the various "onium" states



Dielectron Spectra



Excellent resolution for distinguishing states
(ρ, φ) and (J/ψ, ψ')

Acceptance at x_F = 0
(mid-rapidity)

Good acceptance at low pt
(key for ρ, φ)

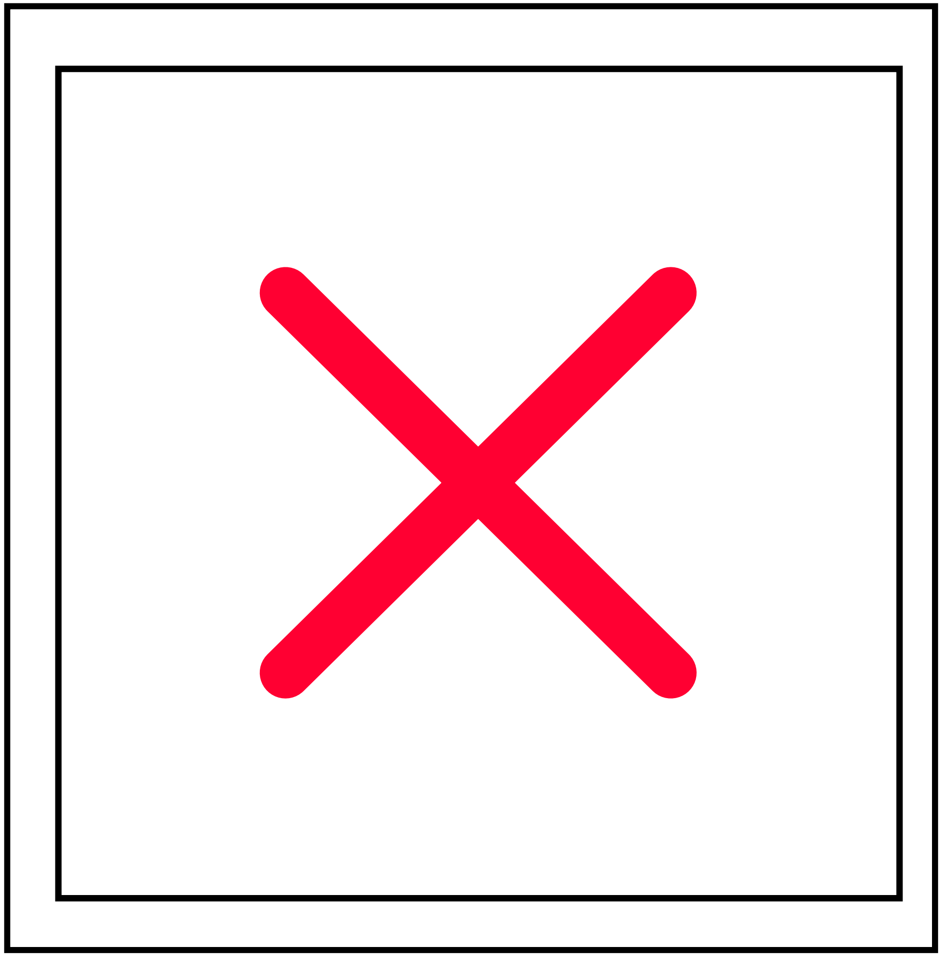
Dimuon Spectra

Excellent statistics on J/ψ

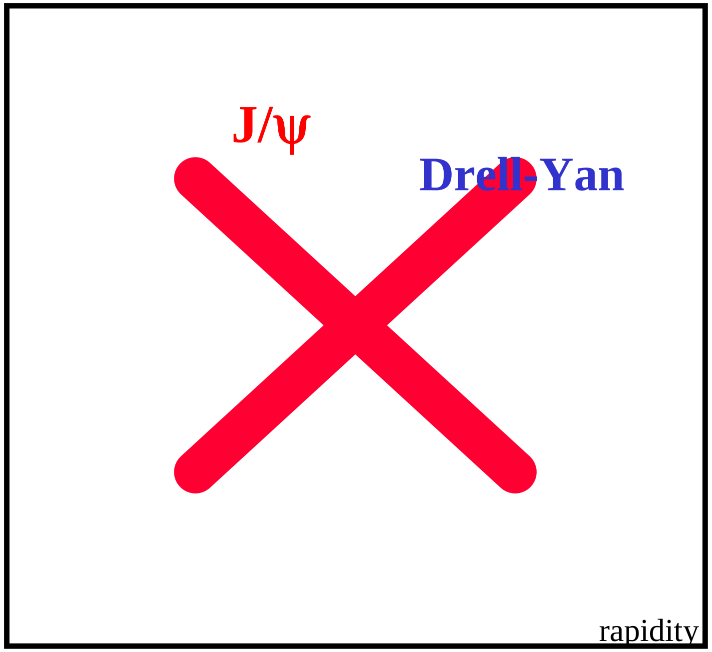
Large Acceptance
(10 x that in central)

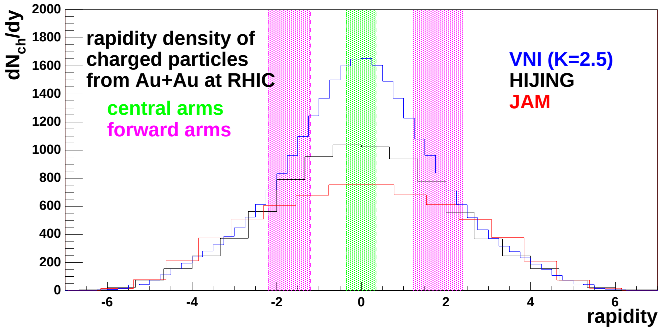
Good resolution for distinguishing states
(J/ψ, ψ')

Acceptance at higher p_t for low mass states ρ , φ



Rapidity Dependence





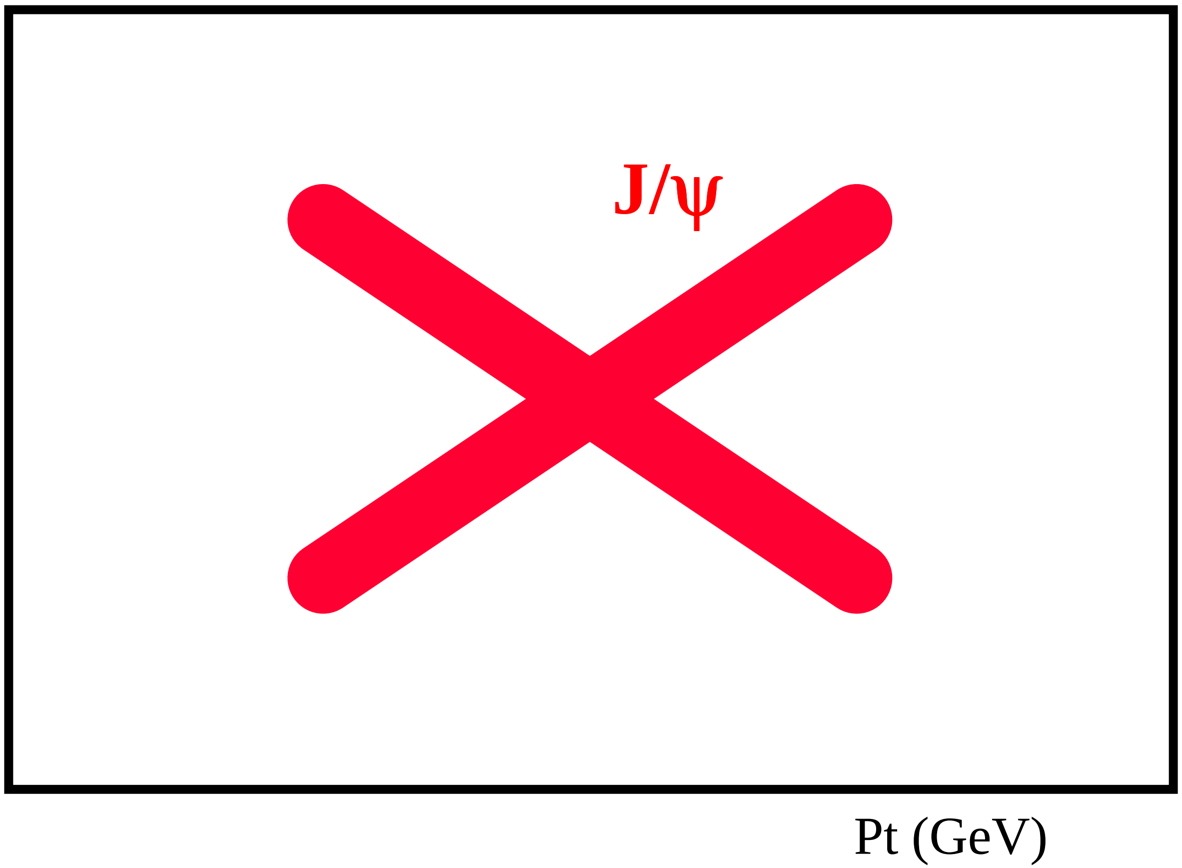
PYTHIA rapidity distribution for J/ψ and Drell-Yan (as an example).

Central (electron) arms and **forward (muon) arms** measure in different regions.

They will be sensitive to parton distribution functions, nuclear effects and different co-mover densities.

Measuring as a function of rapidity (x_F) will be important.

Transverse Momentum



When? When? When?

	$J/\psi\ (\mu^+\mu^-)$	$J/\psi\ (e^+e^-)$	
Year 1 (2000)	**0**	**25**	Assumes 8 weeks at 10% design Energy is 140 GeV, not 200 GeV Only 50% coverage in central arms
Year 2 (2001)	**5.0×10^4**	**1.0×10^4**	Assumes 37 weeks at 50% design Commissioning of muon South arm Commissioning of triggers
Year 3 (2002)	**3.0×10^5**	**5.5×10^4**	Assumes 37 weeks at 100% design
Year 4 (2003)	**6.1×10^6**	**5.5×10^5**	Assumes 37 weeks at **10 x** design Commissioning of muon North arm

Year-1 Configuration

Maximum 8 weeks running.

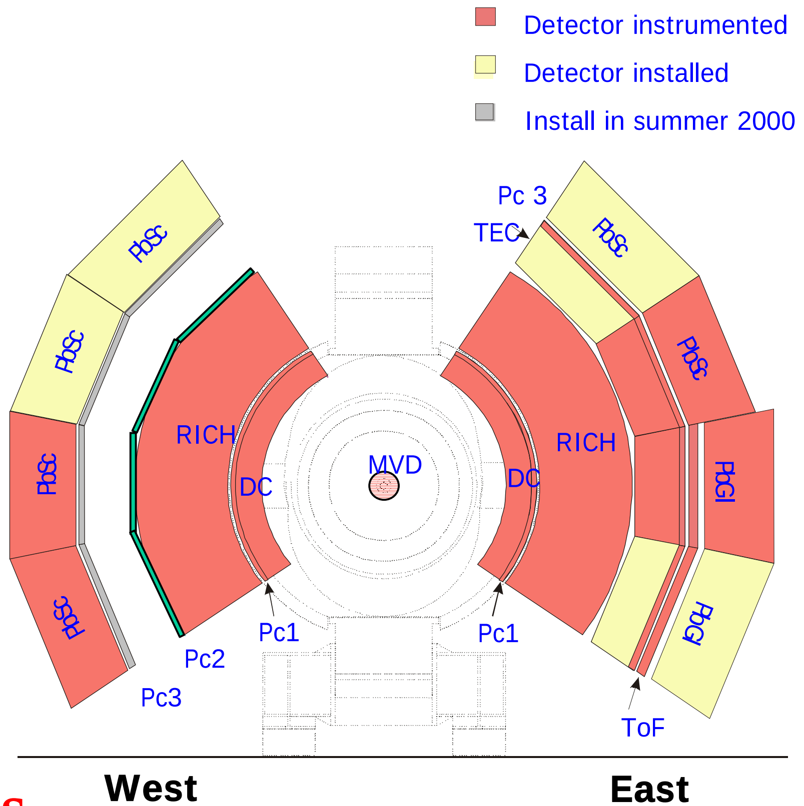
Maximum 10% design luminosity

Central Arm Spectrometers.

Maximum Energy ~ 140 GeV/u

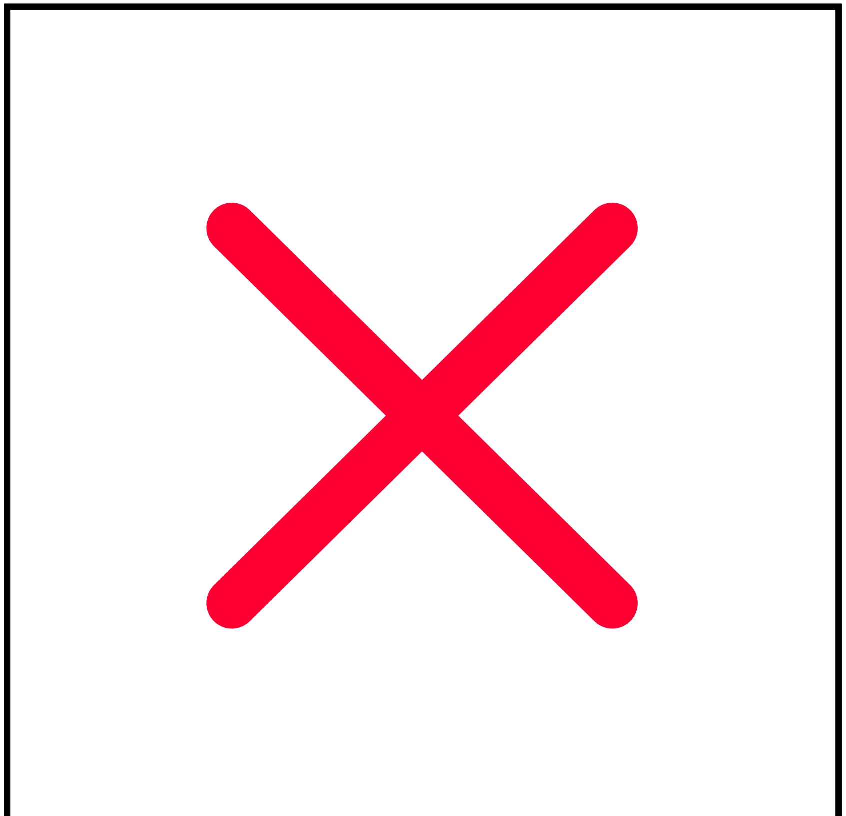
I think we will learn a great deal (see global and hadron physics), but just getting started with leptons.

PHENIX run 2000 configuration

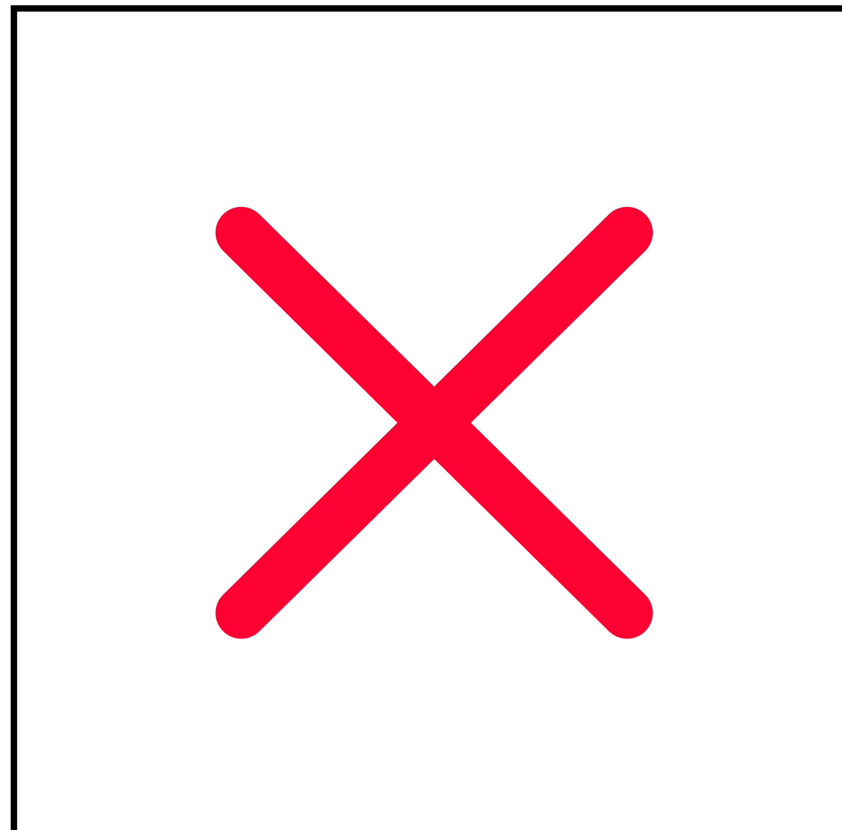


Example Spectra from Muons

Year 2 Results



Year 4 Results



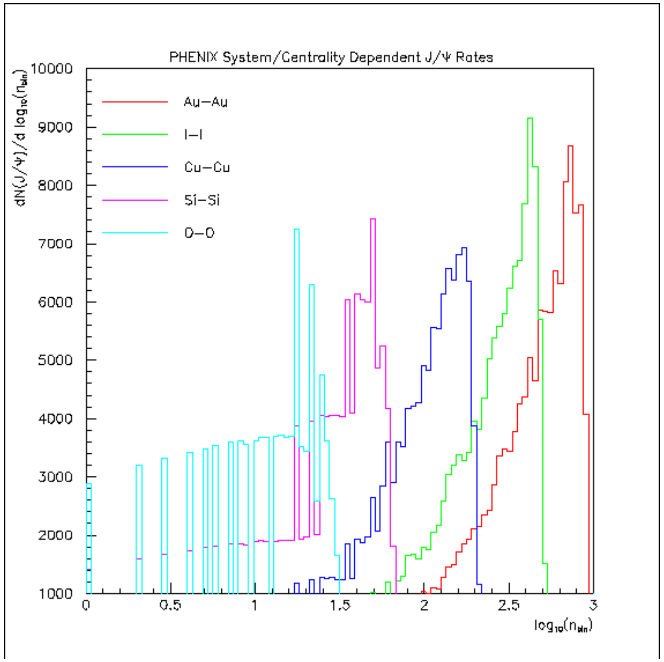
* Year 4 includes both North and South Muon Arms and Level-2 Trigger which makes possible ρ , ϕ physics and discrimination of Y states.

Proposals and Ideas

PHENIX may propose to run many symmetric lighter ion collisions (which have higher maximum luminosity) in addition to Au + Au to best cover a broad range in collision geometry.

All in one year of running

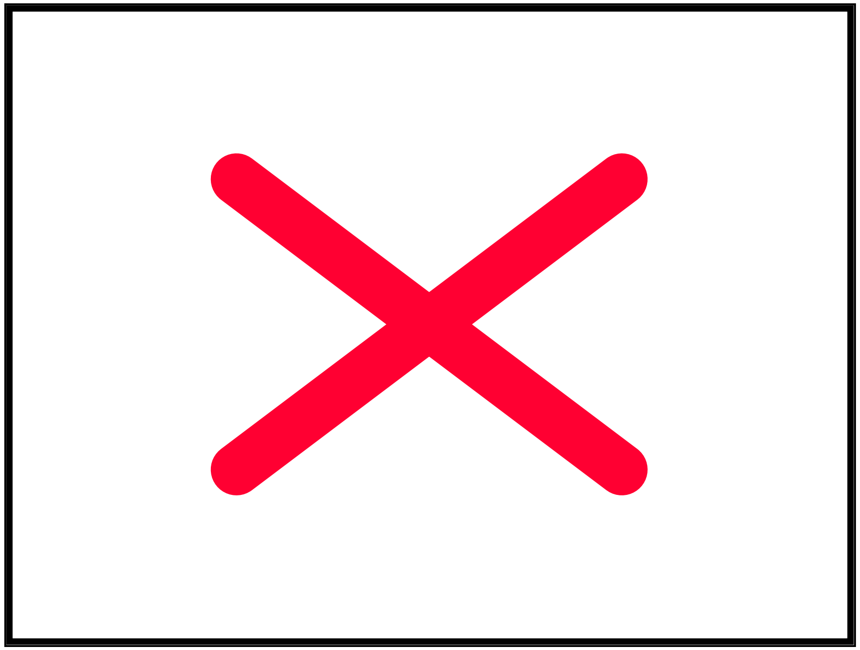
Species	Number of J/Ψ's (0.6 R.Y. - AuAu, 0.1 R.Y. - others)
OO	1.15E+05
SiSi	1.44E+05
CuCu	1.56E+05
II	1.73E+05
AuAu	1.79E+05

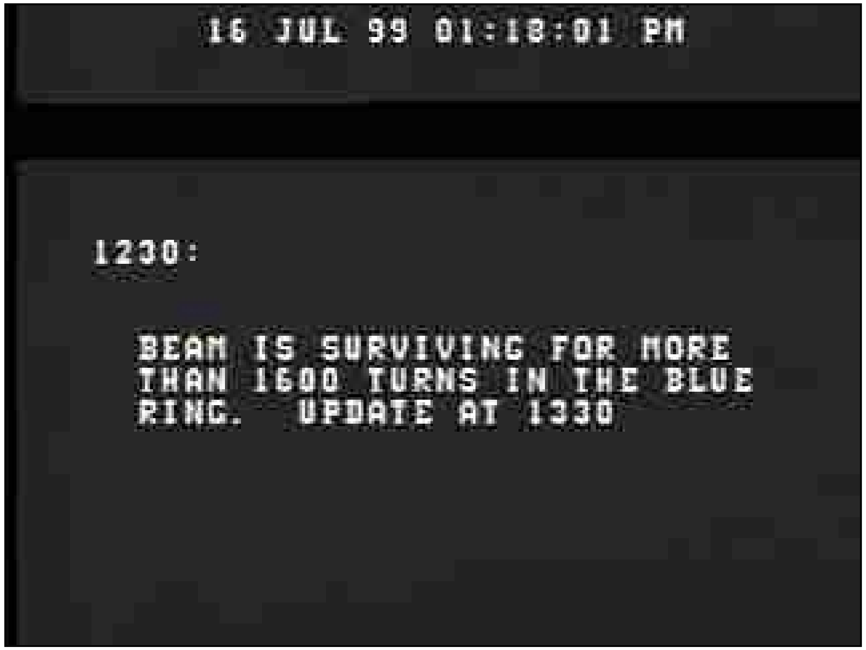


Vince Cianciolo

First Beam

At around 2 am on July 13th, 1999 the first beam made it around the ring. First measured via PHENIX beam-beam and scintillation counters.





Conclusions

Exciting physics coming up soon!!!

Maybe a fancy picture of the beam status